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PULP AND PAPER TECHNOLOGY

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6-2 Paper Machine— Forming Section

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Introduction Paper is a web of fibers forming a three-dimensional network. The predominant method used to make this sheet involves filtration from a dilute fiber suspension in water onto an endless wire mesh that is fine enough to retain most of the fibers. The section of the paper machine performing this function is called the "forming section," and it receives the fiber suspension in a continuous jet from the headbox at 0.1 to 2.0% consistency. It then delivers a self-supporting sheet at 10 to 25% consistency to the press section. The prime functions of the forming section are to deposit the fibers so that a paper of desired quality is produced and to provide the necessary removal of water.

As the position and direction of the fibers in the sheet structure is almost entirely determined by the forming process, it follows that many of the most important quality characteristics of the paper are established here. Properties mainly determined by the forming section are: formation, strength isotropy, fines distribution through the sheet, wire mark, and to a large extent, surface uniformity.

Due to the wide variation in paper properties (tissue, greaseproof, boards, etc.), basis weights (3 to 3000 lb), and speeds (10 to 5000 fpm) used in the industry, the demands on the forming section varies greatly. This has resulted in the development of a number of different types of forming methods, each with its preferred application.

For a better understanding of the present technology, a short discussion of the fundamentals of drainage and forming is needed. In addition to the forming of the mat, the forming section also compacts the sheet and removes water by suction, thus giving it sufficient strength to be transferred to the press section.

THE SHEET FORMING PROCESS

Paper is made by depositing fibers from a dilute suspension onto a fine wire mesh by filtration. The water drains through, while the majority of the fibers are retained by the wire. As the fibers are of about the same size as the openings in the wire, a large number of them pass through in the initial phase. As more and more fibers are retained, they themselves act as a filtering medium, thus causing a progressive increase in retention. The change in retention during the sheet forming process produces a variation in structure and fiber composition through the thickness of the sheet.

During the forming process, the sheet is built up from fibers or fiber aggregates in a generally random manner. The sheet structure is, therefore, critically dependent on the distribution of the fibers

in the water suspension. Knowledge of the properties of dilute fiber suspensions is, therefore, a necessary part of understanding forming.

Fibers are flexible particles normally with a length of 1 to 4 mm, and with a length to diameter ratio mostly in excess of 100 mm. Papers are made from mixtures of fibers with greatly varying dimensions. Above a critical consistency of about 0.05%, these suspensions form three-dimensional networks, due to interaction and entanglement of the individual fibers. In a flowing suspension, the network is normally broken down into aggregates varying in size between 5 to 30 mm called "flocs." "Flocculation" is a dynamic phenomenon in shear flow with fibers moving between flocs. The tendency of fibers to floc and the strength of the fiber network increase with fiber length and consistency. Network strength is at least a third power function of consistency, as shown in Fig. 1. In fluid flow, the fiber network breaks down into smaller pieces when the shear rate exceeds the yield point of the network at its weakest point. Due to the large effect of consistency on network strength, the size and density of the flocs increases rapidly with consistency. Increasing shear rate and reducing the geometrical scale will reduce the size of the flocs, but will in-

crease their density. The uniformity of the sheet formed improves with the reduction of size and density of the flocs and is at its optimum when each fiber is free to move independently. However, in most commercial operations, it is impossible to operate at low enough consistencies, due to the limitations in drainage capacity of the forming section. Forming, therefore, occurs mainly from fiber suspensions in different stages of flocculation. Due to this, consistency is by far the most important factor in determining sheet formation. The longer the fibers, the more important low consistencies are for good formation. While bag papers are currently made at 0.15% consistency from soft wood, kraft groundwood papers can be made satisfactorily at effective consistencies of 0.3 to 0.5%. Figure 2 illustrates the relationship between sheet formation and forming consistency. For a given set of conditions, the drainage capacity of the forming section determines the forming consistency, and thereby, the paper quality.

Turbulence breaks down the fiber network. Increasing turbulence reduces the size of the flocs, but increases their density. The size of the flocs can also be controlled geometrically. These methods are being used in the headbox to deliver a well deflocculated suspension to the forming area. As forming normally occurs under shear-free conditions, turbulence dies very rapidly with larger flocs reformation. Only by setting the sheet close to the headbox can advantages of deflocculation by high turbulence be used to any significant degree. This method is being used in all successful applications

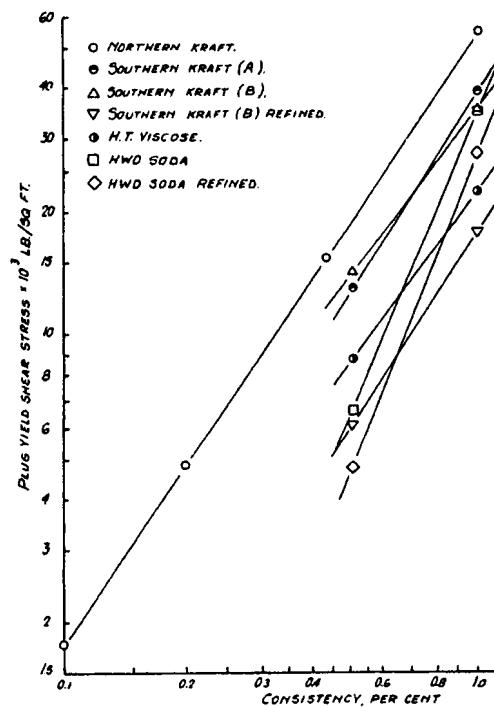


Fig. 1 Fiber network strength. (Courtesy P. Wrist)

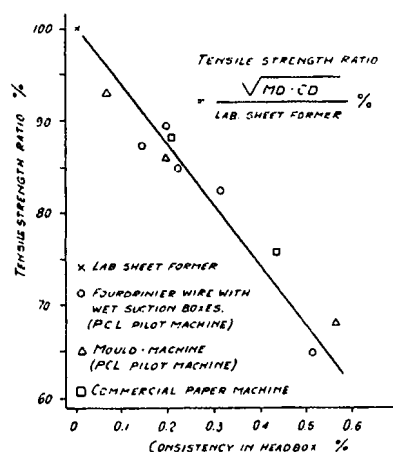


Fig. 2. Illustration of the relationship between sheet strength and forming consistency. (Courtesy S. V. Papperstidning)

of confined area formers, such as suction breast roll formers and different types of twin wire formers. This makes it possible to form satisfactory sheets despite relatively high forming consistencies caused by the limited drainage capacity of these formers.

Even if the fiber flocculation in the suspension entering the forming area is the dominating factor as regards formation, there are many mechanisms in the forming process itself that have very significant effects on the paper structure. These will be further discussed under each type of former. One general remark should be stated now, as it is applicable to every process; any mechanism breaking up an already formed sheet is detrimental to the quality of the paper.

DRAINAGE

Initially, only the wire resists the flow of water being removed. As fibers are deposited and the fiber mat grows, the resistance to flow increases. To initiate and maintain drainage during the forming process necessitates the application of a pressure gradient in the forming area. The time and pressure available determines, together with the drainage properties of the pulp, how much of a given sheet can be formed under a given set of conditions. The drainage process (as applied to forming) has been the subject of extensive studies. These show that it can be described through modifications of relationships established for flow through capillary systems. Due to the effect of differential compression and retention on the drainage cycle, together with the complexity of the fiber systems, the application of this knowledge to practical problems have been very limited. Recent work (based on dynamic drainage tests under constant pressure differential and at paper making consistencies) have produced useful empirical formulas to describe drainage during the forming process. The following formula illustrates drainage capacity:

$$t = G/S \times (\Delta Pm)^{-n} W^a \mu$$

where

t = time needed to form a fiber mat of weight W

G = drainage constant, characteristic of pulp

S = consistency of suspension

Pm = pressure drop across mat

n = constant characterizing the compressibility of the mat (0.3 to 0.6)

a = constant characteristic of type of pulp and beating (2 to 3.5)

μ = viscosity of water

This formula is valid only for sheets heavier than about 30 g/m², when retention equilibrium has been reached.

The time needed to form a sheet increases at least with the square of the basis weight and is proportional to the drainage constant of the pulp. (Figs. 3 and 4.) The drainage constant can increase more than a thousand times, due to beating of the pulp and increases also with retention of fine material. This together with the very large variation in basis weights being produced illustrates why some products such as tissue can be made at very high speeds (5000 fpm), despite a very short forming length, while products like building board are made at speeds of 30 fpm. The large variation in drainage times needed has produced different types of drainage processes for different products. Forming the sheet between two wires permitting drainage both ways reduces the forming time to at least one-fourth of the time needed for single wire forming. This permits forming sheets over small distances at high speeds. Heavy sheets from highly beaten stock can only be made by combining a number of thin sheets, as is the case for many board qualities made

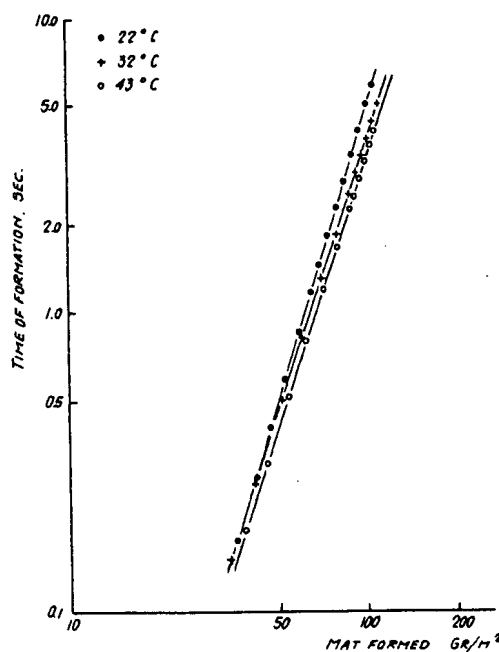


Fig. 3A. Time of formation, sec vs basis weight at varying temperatures.

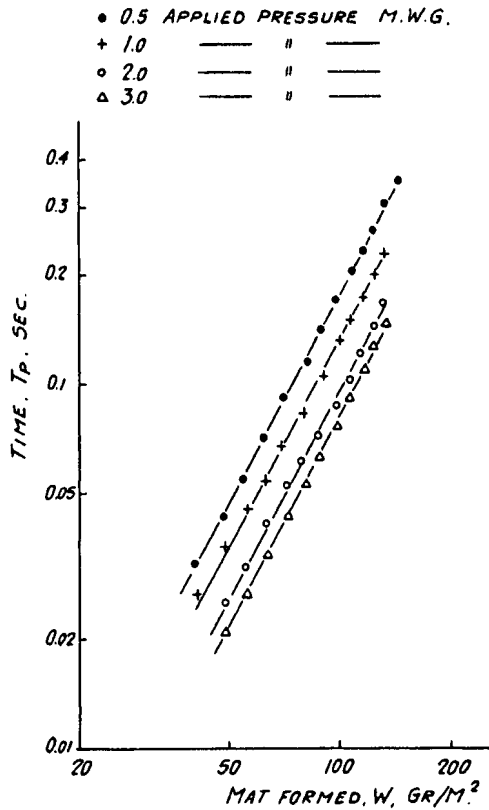


Fig. 3B. Time of formation, sec vs basis weight at varying pressures.

on cylinder board machines having a large number of forming units. Drainage time is inversely proportional to the forming consistency. With a given forming device, heavier grades are always made at higher consistencies, due to the limited drainage capacity available. The effect of consistency on sheet quality limits the consistency that can be used for a given product and makes it advantageous to have high drainage capacity available. As a typical flow phenomenon, the drainage time is proportional to the viscosity of the water; therefore, it is reduced with increasing temperature.

Increasing the pressure drop available for drainage reduces the drainage time, but due to the counteracting effect of compression of the mat on drainage resistance, the effect is reduced and varies for different pulps. The effect is also less, the more compressible the sheet, and it varies between exponents of 0.38 to 0.52 for different pulps.

The empirical drainage equation can be rewritten to demonstrate the meaning of drainage capacity and its importance as a limiting factor determined by the

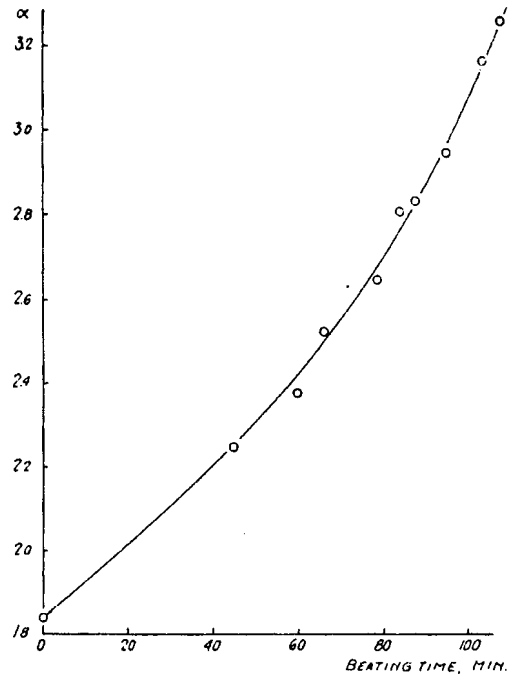


Fig. 4. Effect of beating time, min on exponent α in drainage equation $t = G(\dots P_m)^{-\alpha} W$, where W is basis weight.

equipment available:

$$l\Delta p^n = PrGW^a - 1/S \quad (2)$$

where l = suction length

Pr = production per width of machine

The term drainage capacity is here defined as $l\Delta p^n$. For some drainage elements, l is a constant, and Δp can be controlled up to a maximum determined by the equipment; as n is defined by the product made, $l\Delta p^n$ maximum can be defined as the drainage capacity of the machine. In some cases, both l and Δp are not only functions of the equipment, but of machine speed, product made, wire tension, etc. Even under these conditions, the drainage capacity can be considered as defined by the equipment. Considering $l\Delta p^n$ as an equipment characteristic that defines the maximum drainage capacity of the system, we can determine its effect on the performance of the forming section.

For a given product, G , W , and a are normally defined, and S maximum is limited by product quality. Drainage capacity then determines the production of the machine. Improving paper quality by reducing consistency immediately reduces productivity. Only by increasing the drainage capacity of the

forming section can higher production be reached or a better product obtained.

At constant drainage capacity, higher production is possible at lower basis weights with constant pulp quality and forming consistency. On the other hand, at constant production, the lighter sheet can be made at lower consistencies, thus giving improved quality.

For certain dynamic drainage elements, such as foils and table rolls, the drainage capacity decreases rapidly with decreasing speed and increasing basis weight, thus requiring a much larger reduction of production for heavy grades than for drainage elements with constant drainage characteristics. As the type of drainage elements also effects G and a , this further complicates the comparison and the evaluation.

The fundamental importance of drainage capacity in determining both quality and production per unit width has resulted in determined efforts to develop better drainage tools with higher drainage per wire length, including the development of twin wire formers.

FORMING METHODS

The large variation in drainage conditions under which paper products are being manufactured has resulted in the development of a multitude of forming methods, each with its specific area of application. These forming methods will be discussed under the heading of open wire formers, cylinder machines, suction breast roll formers, and twin wire

formers. As a special case, the use of some of these forming methods in multiple formers will be discussed.

OPEN WIRE FORMERS—THE FOURDRINIER WIRE SECTION

The fourdrinier wire section or the open wire former is the oldest and still most widely used forming method. It is called the open wire former because the fiber suspension is deposited on top of an endless wire running horizontally, with drainage elements positioned under the wire. The configuration of an open wire former is shown in Fig. 5.

The fourdrinier wire section is still the most flexible of all forming methods, both as regards types or paper manufactured and its ability to control paper quality. Open wire formers are used for the heaviest types of boards, made at very slow speeds, as well as for reasonably light sheets made at speeds up to 3000 fpm. It has by far the largest drainage capacity of all formers used today. The open wire former is limited in speed, due to the open surface, and will most likely never be used for speeds in excess of 4000 fpm. Products demanding higher drainage capacity than can easily be built into an open wire former are produced on multiple forming devices.

General Description The fourdrinier wire section consists of a rigid structural frame with large side beams for the support of the elements defining the

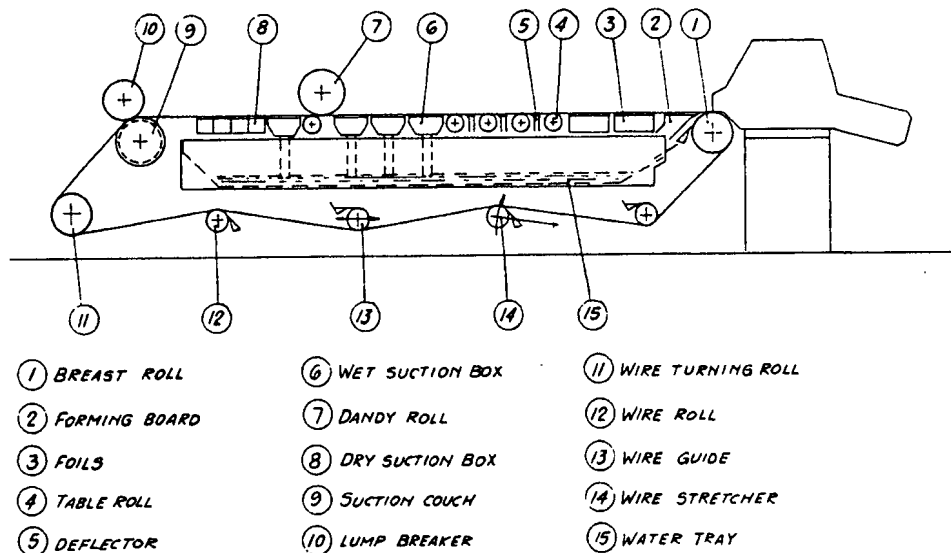


Fig. 5. Configuration of an open wire former.

run of the fourdrinier wire. The large turning roll underneath the headbox at the front end with a wrap in the order of 180° is called the breast roll. The roll at the far end of the wire section is called the couch. The top part of the wire loop between the breast roll and the couch runs in a straight, mostly horizontal run over different types of drainage elements and supporting structures. These elements may be plain or grooved table rolls, single or double deflectors, foils, Wet Suction Boxes, and/or dry suction boxes. Between the couch and the breast roll on the lower part of the wire, there are a number of wire return rolls needed to support, drive, stretch, clean, and guide the wire. The elements defining the wire run are all sturdily built to give a deflection small enough to avoid wrinkles in the wire. The rolls with the largest wrap, therefore, have the largest diameter. The size of the rolls increases rapidly with machine width and machine speed. Table rolls are normally dimensioned for one-half critical speed. All rolls are dynamically balanced for their design speed. The rolls are normally made of mild steel and covered with hard rubber or fiberglass reinforced plastics.

The framework is lined with stainless steel, as are all parts in touch with water. Inside the wire, there are stainless steel trays for collecting the water draining through the wire and for directing it out of the wire.

Modern wire sections are all made for easy wire change, using either a cantilever or roll out system permitting the endless wires to be put on without removing the elements in the wire section. On older machines, all elements had to be removed for the installation of a new wire. The cantilever system uses removable front supports. When these are removed, the wire section is supported by special beams in the back side. The wire previously draped on a movable carriage can then be slipped over the wire section. In the roll-out type, the whole wire section is rolled out into the aisle, except the couch which is normally cantilevered. The wire is then strung in place over the couch roll, and the assembly is rolled back in place.

The wire section is sometimes built to enable the wire at the forming end to move in a lateral shake motion with controlled amplitude and frequency shake. The forming and support elements are supported by a separate rail that can be shaken.

The wrap around the couch is normally, on old machines, a little less than 180°. On most modern machines, however, the wrap is less than 90°, due to the forward drive roll. The forward drive roll is needed to give more in-drive points for driving the wire and also to provide a means for removing the

sheet from the wire on a free wire run (either in an open draw or by transfer directly to a felt.)

Power is needed to drive the wire to overcome the friction between the wire and stationary elements like deflectors, foils and suction boxes, and also the friction in roll bearings and between rolls and doctors. In addition, hydrodynamic forces are created between rolls and the wire where the rolls are used for drainage. The power needed can easily be found in TAPPI Technical Information Sheets. To transmit the power to the wire, the couch, and the forward drive roll, sometimes one or more wire return rolls are driven.

Fourdrinier Wires The wire is a finely woven metal or synthetic wire cloth normally woven as an endless band. The strands of the wire are usually made of specially annealed bronze and brass that are woven together into weaves usually from 45 to 85 mesh. The mesh varies with the paper made and has to be fine enough to retain most of the fibers being used. Papers like cigarette and condenser papers are made on even finer wires. Coarser wires are used for board and pulp sheets. Different weaves are used in order to obtain maximum life or minimum wire marking. Wires are often ground to reduce wire marking. (See Paper Machine Wires, Ch. 6-8).

Abrasion, bending fatigue, corrosion, and accidents combine to determine the life of the wire. It normally varies between 5 and 50 days for bronze wires operating on normal paper grades. However, plastic wires used on pulp machines have reached lives in excess of two yr. Wires represent a considerable cost, and great efforts are being made to reduce it by increasing wire life. Abrasion and corrosion are the two most important causes of wire wear. Abrasion occurs when the wire passes over stationary surfaces and is greatly effected by the presence of clay, sand, etc. in the pulp. By selecting material on deflectors, foils, suction boxes, etc. that combine a low friction coefficient with hardness and by preventing grit from being embedded in the surface, wear through abrasion can be radically reduced. This has resulted in the use of very smoothly polished hard covers, silicon carbides, etc. for suction box covers for most high-speed machines where wear is most important. Other materials such as high-density polyethylene with low-friction coefficient and high wear resistance are being used for medium to slow speed machines. Wear is easily distinguished by the flattening of the knuckles on the inside of the wire.

Corrosion often seriously reduces wire life. In

many instances, corrosion can be overcome by adding corrosion inhibitors to the whitewater system. Both stainless steel and chrome coated wires are now in use to overcome the effect of corrosion and also to increase wear resistance.

Both corrosion and wear can be greatly reduced by changing from metallic wires to synthetic fabrics. After over a decade of intensive development, the fabrics are today being used extensively for slow and medium speed machines. These wires are mainly of the multi-filament type. The recent introduction of monofilament fabrics with higher rigidity seems to make it possible to apply fabric wires even to the largest and fastest machines. The problems of too much elongation and insufficient dimensional stability and rigidity have now been mainly overcome, and it seems safe to predict that plastic wires will dominate the market within a reasonably short time.

DRAINAGE ELEMENTS IN THE FORMING AREA

All drainage on an open wire fourdrinier occurs as a result either of the pressure exerted by the fiber suspension itself, which in most cases is negligible, or by vacuum created under the wire by different types of drainage elements. The drainage elements most commonly used are table rolls, foils and wet suction boxes. The characteristics of these elements will be further discussed below. Inertial forces find limited application as well as pressure applied on top of the wire.

Table Rolls Initially table rolls were used because they offered the best way to support the wire with the least resistance to moving it. It was only in 1956 that Wrist and Burkhard showed that the table roll creates a vacuum in the water filled nip between wire and roll, thus making them very powerful drainage elements.¹ The shape of the suction curve generated by a table roll is shown in Fig. 6. Experiment and theory have shown that the peak suction is only dependent on the machine speed and is equal to the head in the headbox.

The maximum suction, S_{max} , is given by the formula:

$$S_{max} = \frac{V^2}{2g} \quad (3)$$

This equation is only valid up to about 2500 fpm, when the peak suction reaches the partial vapor pressure of the stock. It is obvious that the vacuum generated by the table rolls increases very rapidly

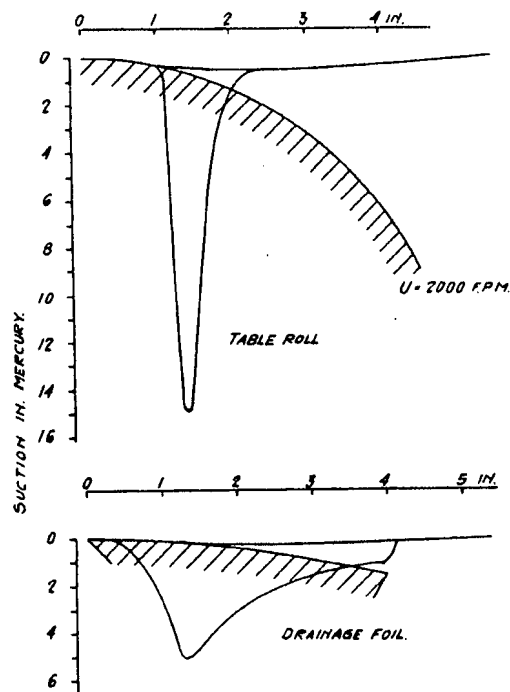


Fig. 6. Shape of suction curve generated by a table roll and a foil. (Courtesy P. Wrist)

with speed and reaches very high values already at 1000 fpm. In a drainage section consisting of table rolls, drainage occurs in short intense pulses separated by areas of zero suction. The length of the suction pulse varies with the amount of water extracted at that point and with the size of the nip that water can fill. The nip width is proportional to the diameter of the table roll and inversely proportional to the drainage resistance of wire and fiber mat. The nip width (and thereby drainage) decreases very rapidly with mat build-up and, therefore, down the wire section, as shown in Fig. 7. As the average nip width is less than 1 in. even for large table rolls, only about 5% of the wire is used for drainage in a table roll section. The short, intensive, widely spaced, pulses tend to deform the wire, thus creating very potent vertical acceleration forces. The pulses also disturb the sheet, form ridges, and spout at high speeds. These disturbances are limited by using deflectors to support the wire between the rolls or by grooving the table rolls. This greatly reduces the forces acting on the wire and the drainage at each roll.

The amount of water removed by a table roll can be expressed by an empirical formula:

$$q = D \cdot U^k / F^2 \quad (4)$$

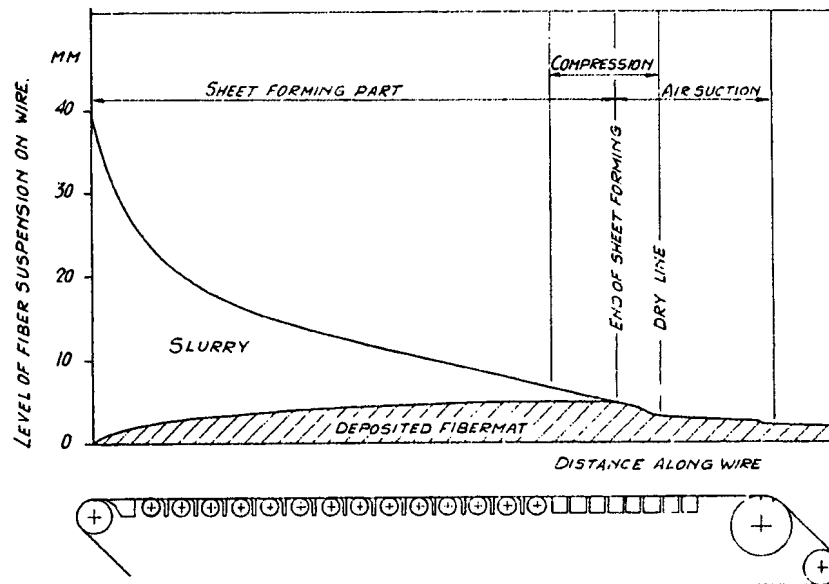


Fig. 7. Drainage and mat build up on open wire former with table rolls.

where q = water removed by a table roll per unit time and width.

D = diameter of roll.

U = wire speed.

F = a drainage factor determined by the sag of wire, air content, thickness and porosity of mat (main factor), stock freeness, headbox consistency, degree of flocculation, and evenness of formation.

K = exponent defining the effect of speed on drainage, characteristic of type, and quality of pulp.

K has been found to be 0.3 for kraft pulp and 1.2 for news. F has been found to increase linearly with basis weight. As F is dependent on a very large number of factors, it can only be used to describe the drainage, but not to predict it. The large number of variables involved in table roll drainage makes it very improbable that any generally applicable solution will be found.

The drainage equation for table rolls shows that drainage will increase proportionally with table roll diameter and also increase faster with speed, the less compressible the sheet. As F is almost proportional to basis weight, drainage decreases rapidly the further down the wire the roll is located. Due to this, increasing the number of table rolls over 15 to 20 gives very little additional drainage. This characteristic of table roll sections defines a limiting drainage capacity almost exclusively determined by

product made and speed run. Due to this, it is possible to list limiting consistencies for almost every product made on table roll sections. To go below those consistencies and radically improve formation necessitates drainage elements with other criteria.

The above demonstrates the inflexibility of the table roll as a drainage element. The vacuum is a function of machine speed. Drainage is determined by roll diameter, speed, and drainage resistance; all are factors outside the control of the operator. The only control is achieved by lowering or raising rolls, grooving rolls, or exchanging rolls of different diameters; all are actions of a discontinuous kind. This prevents control over the drainage curve, which is important in controlling sheet directionality.

Foils A foil is a stationary blade held in contact with the wire at the front end and diverging from the wire at the trailing end at an angle varying between 2 to 5°. Figure 8 shows a typical foil. The foil with its diverging nip uses the same hydrodynamic principle as the table roll to create its vacuum. Due to the stationary member of the nip, the peak suction is less and amounts to between a half and one-fifth of that of the table roll, depending on the angle of the foil (Fig. 6). The peak vacuum as for table rolls is proportional to the square of the wire speed. This makes the foil an inefficient drainage element at slow speeds. Because of its lower vacuum, the rate of drainage is considerably less than for table rolls; however, the nip is normally much longer, which

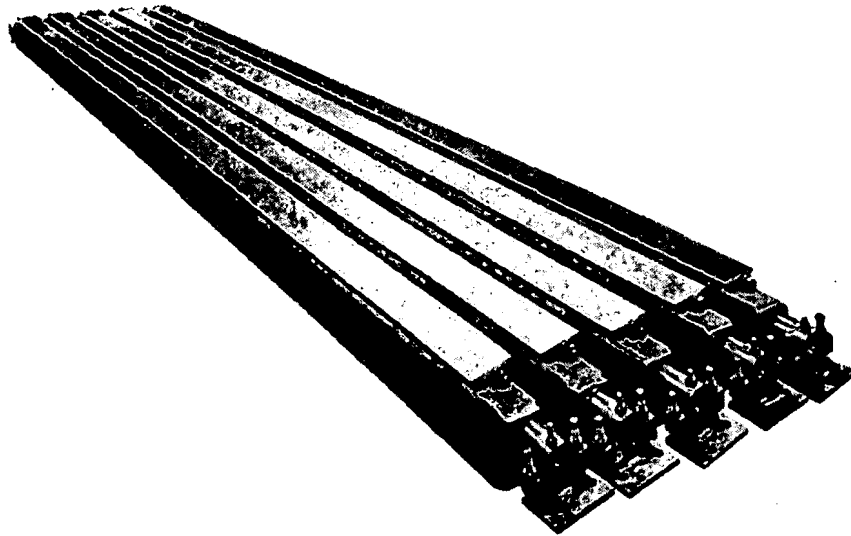


Fig. 8. Typical foil (Huyck).

offsets most of the loss in drainage capacity. The angle of the foil and its position determines the amount of disturbance and drainage produced. By varying foil angle, the drainage curve can be controlled as well as the action on the wire. The disturbances are very much lower than those created by the table rolls; but many cases are known where severe problems have been encountered with foils mainly due to interaction. The lower disturbance has made it possible to increase the speed of open wire tables using foils.

Despite the fact that foils have less drainage capacity than table rolls, it is possible to increase the total drainage capacity of the wire section, because so many more foils can be installed in the same space. Foils are normally 2 to 8 in. long, depending on their location. Short foils are used where small amounts of water are removed, while long foils are useful at high drainage rates. The long foils are normally used close to the headbox as individual units, while further down the table, shorter foils normally are combined into boxes containing 4 to 8 foils. Intermediary units with two foil blades are also used. Recently, vacuum foils have been introduced to improve drainage at slow speeds, and heavy weights are used where foils are inefficient, just as table rolls.

Today, foils are normally built for easy exchange of the blades during operation, to enable the correct foil angle to be used, as grades and conditions are changed. The exchangeability also permits the

blades to be kept in good geometrical condition, which is a must for the effective use of foils. Some of the larger single or double foils are built so that the angle can be adjusted mechanically during operation.

As the action of the foils is solely dependent on their geometry, good geometrical definition is a necessity. Foils must be sturdy to control deflection and vibrations. The blade must be free of distortion and give exactly the same foil angle across the machine. The material should be wear resistant. Today's foils meet these requirements, which is necessary for their wide-spread acceptance. The dominant material for the foil blade is high-density polyethylene on units built for easy replacement of blades. Permanent foils are all provided with a hard cover on the front part that runs against the wire.

Foils are being used more and more on open wire tables and are replacing table rolls. From being used to replace part of the tables, the trend is now towards complete foil tables, or in combination with wet suction boxes. Hundreds of such installations are now in operation on almost every grade of paper, including high-speed newsprint machines.

The advantages of the foils over table rolls are higher drainage capacity, better control of drainage curve, and disturbance level. This results in better formation, less two-sidedness, better retention, and increased speed limit. Foils, therefore, represent a substantial improvement over table rolls and are

expected to replace table rolls to a larger and larger extent. However, foils still possess limited drainage control and limited drainage capacity which is very speed dependent. They will therefore, most likely be used together with drainage elements like wet suction boxes.

Wet Suction Boxes The need for a drainage element with large drainage capacity, ease of control, and absence of disturbances led to the development of the wet suction box.^{2,3} The wet suction box is a slotted box with an open area, normally in excess of 60%. It is built to handle large amounts of water and to operate at vacuums below 3 ft of water. Figure 9 shows a typical KMW wet suction box. It is provided with a number of manifold drop legs sealed in the wire tray to enable it to handle the water removed. Other arrangements can also be used. The vacuum is obtained by connecting the box to a vacuum system. The vacuum in the box can be varied between the maximum available, due to the distance between the seal level and the vacuum outlet, and zero, either manually or automatically. Normal vacuum levels are 1 to 2 ft of water. The top is normally made of high-density polyethylene, which has good wear resistance and a low friction coefficient. The wet suction boxes must be operated with sufficient air space under the wire to prevent any splash-back from hitting the underside and disrupting the sheet.

The drainage of wet suction boxes follows closely the equation (1) for drainage under constant pressure. Suction length and wire speed determine the drainage time, and the pressure differential is independently controlled and is not a function of wire speed. Drainage capacity increases proportionally with suction length and as a 0.38 to 0.52 power of vacuum, dependent on the type of pulp used. The

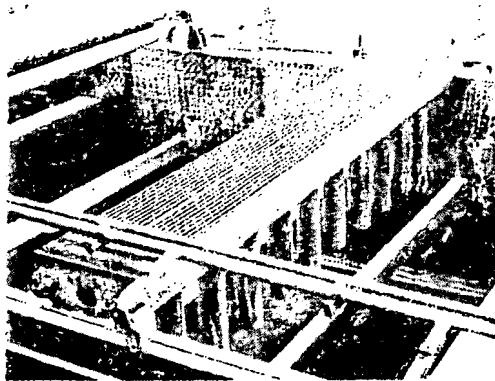


Fig. 9. Typical KMW wet suction box.

drainage capacity per wire length of wet suction boxes at normal vacuums is very much greater than either for table rolls or foils, independent of speed and grade made. The relative advantage of wet suction boxes in drainage rate over table rolls and foils increases with decreasing speed and higher basis weight, but is considerable even at the highest speeds and low basis weights. Wet suction boxes make it possible to build wire sections with very much larger drainage capacity and with shorter wire length. The limiting consistencies established for table rolls can be substantially reduced, enabling much better paper to be made.

Wet suction boxes permit full control of the drainage curve by manipulation of the vacuum. This is important on machines where large variations in directionality in paper properties is desired.

With wet suction boxes, the sheet is formed at low vacuum and without disturbances. The absence of disturbances removes the speed limitation present for table rolls and foils, and it also insures much improved retention, and thereby also reduces two-sidedness. Figure 10 shows the filler distribution for similar grades made with table rolls and wet suction boxes. Retention over wet suction boxes is practically independent of machine speed, thus making it possible to produce papers with high fines and filler

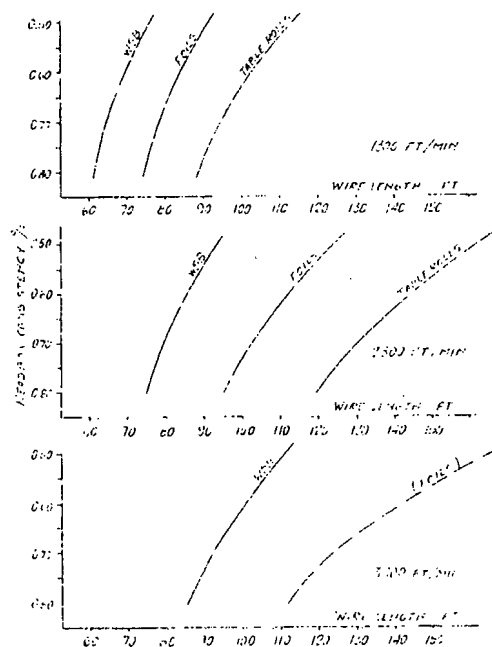


Fig. 10. Headbox consistency for newsprint vs. wire length for table rolls, foils, and wet suction boxes.

EXHIBIT 1

PAPER MACHINE—FORMING SECTION

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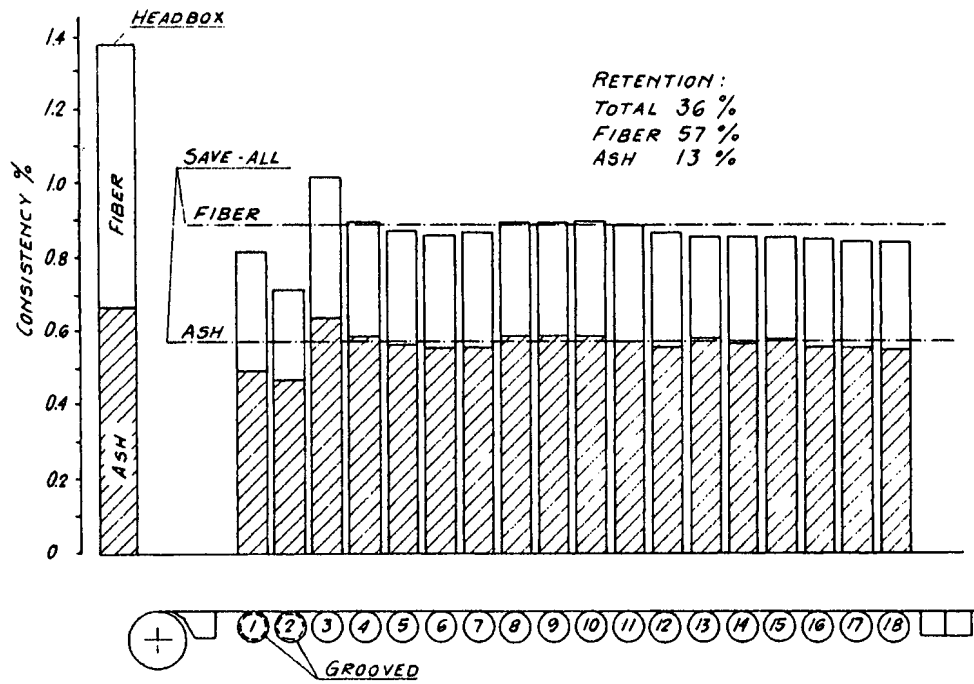


Fig. 11A. White water consistency along wire with table rolls as forming elements for an offset paper with 10% ash.

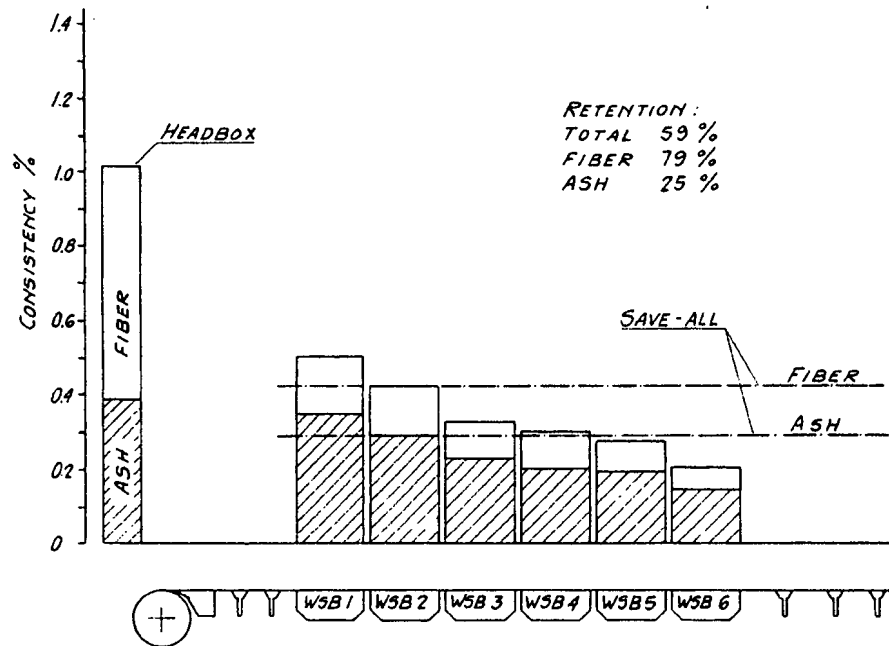


Fig. 11B. As in Fig. 11A, but with table rolls replaced by wet suction boxes.

content at high speeds. Newsprint made on wet suction boxes at 3000 fpm has a retention of 80%, while 50% is normal at 2500 fpm with table rolls. Figure 11 illustrates the difference in retention between these two elements.

Breast Roll and Forming Board The breast roll supports the wire below the headbox. The breast roll is followed by a forming board initially installed to support the wire between the breast roll and the first table roll. The forming board is normally made of five to six wide plastic strips with slots in between through which water can drain. These strips are supported by a sturdy stainless steel box. The forming board is set as close to the breast roll as possible and normally $\frac{1}{8}$ in. below the crest of the breast roll.

The area of the forming board and breast roll is critical as the jet from the headbox lands here and initial drainage starts. The jet should preferably be set gently on top of the first top of the forming board. This insures that small variations in point of impact of the jet on the wire across the machine has no effect on drainage. However, very often with limited drainage capacity, the jet hits the wire early enough to fill the nip created between the breast roll and the wire. Under these circumstances, the breast roll acts as a giant table roll removing large amounts of water. Breast roll discharge, however, lowers retention, increases wire mark and directionality, increases flow disturbances from the headbox and should, therefore, not be used unless necessary in order to make a satisfactorily formed sheet.

Only gravity drainage occurs over the forming board, which is beneficial in order to avoid setting the sheet too close to the headbox, as this normally gives a directional sheet. When directionality is needed, the forming board should be built for suction and the sheet set immediately with a reasonable difference between jet and wire speed. The forming board allows disturbances from the slice to die down.

Deflectors Deflectors, either single or double, are used as support for the wire between table rolls and to prevent the water taken out by the table roll ahead from entering the nip of the next. Stable and rigid deflectors fitting evenly across the wire are necessary for efficient operation of table roll sections above 1000 fpm.

Suction Boxes The drainage elements used in the forming area usually produce a sheet of 1.5 to 3% consistency. To further dry the sheet to the 15 to 25% needed for handling to the press section, it

is necessary to subject it to higher vacuums for compression and to pull air through the structure. This function is performed by suction boxes, rotabelts, and the couch.

The suction box normally is a 12 in. wide trough with a slotted or perforated cover made out of special low-friction materials. High-speed machines use silicon carbides and other hard materials to reduce friction and wire wear. For machines at lower speeds, high-density polyethylene is the most used material. Vacuums of between 2 to 10 in. of Hg are normally used. The suction box vacuum and length has to be sufficient to insure that air is sucked through the sheet. Normally, wire sections have between 5 to 10 twelve in. suction boxes. The lowest possible vacuum should be used to insure that air will pass the sheet. The dryness of the sheet is determined by the highest vacuum used.

The suction boxes are normally connected to a vacuum system provided with controls to keep constant vacuum.

Suction boxes are normally oscillated to prevent the wearing of grooves in the covers. With the use of hard covers, this practice is no longer justified. A preferred arrangement is to oscillate the wire by giving the guide a sinusoidal motion.

Some heavy grades of paper and pulp that are difficult to drain need a high vacuum over a substantial length to accomplish the compaction and suction of air through the sheet. To accomplish this with ordinary suction boxes creates too much friction, thus forcing the development of rotary suction boxes and rotabelts. With the low-friction hard covers available, rotary suction boxes are no longer necessary, but as they are still in use, some description is warranted. The rotary suction boxes are stainless steel boxes divided into several compartments and covered by endless slotted rubber belts moving with the wire. Normally, rolls at both ends guide and drive the rubber belt, which due to water lubrication has a low friction against the sheet box. Very substantial reduction in couch load has been reported, due to installations of rotary suction boxes.

The most efficient means of drying up the paper in the wire section is the suction couch. By making it possible to apply high vacuums to dry the sheet, the speed could be radically increased on open draw machines. Vacuums up to 20 to 25 in. Hg are used; they give paper drynesses up to 25%.

Suction rolls are made from strong, noncorrosive materials, usually centrifugally cast bronze alloys or stainless steel (Fig. 12). The face of the shell is drilled to cover the maximum sheet width with holes

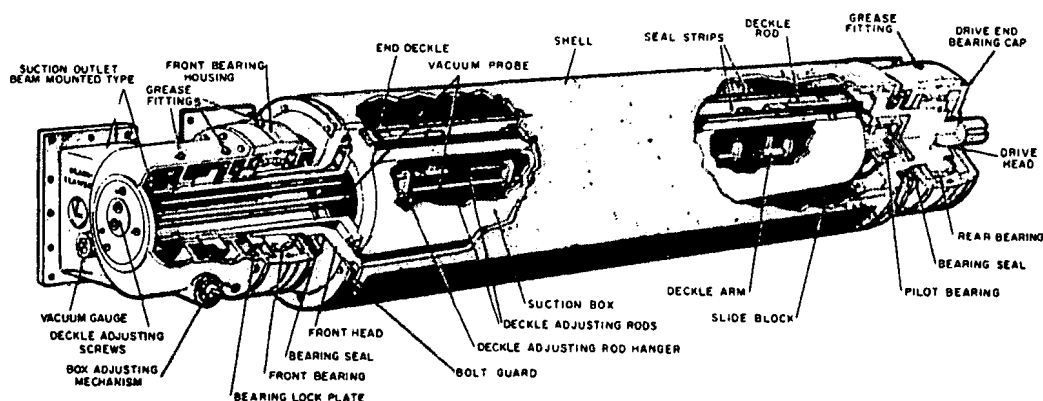


Fig. 12. Cut-away of suction couch roll.

countersunk to give the largest possible open area. A stationary suction box normally made of cast iron is located inside the roll and supported by roller bearings. The suction box is held against the inner surface of the rotating shell. The box is sealed against the shell by pneumatic or spring loaded sealing strips. The end seals are adjustable to account for changes of sheet width at the couch. Suction couches are sometimes provided with one low and one high vacuum box.

Rotating rolls with high vacuum have been a serious noise problem, due to the noise generated by air flowing back into the evacuated holes. The combination of restricted flow to the holes and the design of a suitable hole pattern has reduced the noise to an acceptable level.

Suction couches are today standard for most machines and are necessary for open draw machines where the dryness of the sheet determines its strength, and thereby, the runnability of the machine. For pick-up machines where the sheet is transferred to a felt by suction or adhesion, the dryness of the paper is of less importance, but suction couches are still used and considered necessary.

On very light easy draining papers (like tissue) that are always run with pick-up arrangements, suction couches are not required. Here the couch is normally a grooved roll that makes it possible to perform the pick-up against the roll without crushing.

Lump Breaker Roll When the dryness of the sheet leaving the couch is especially important, a lump breaker roll is normally used. This roll presses against the couch over the suction box, compressing the sheet, and raising the vacuum, thereby improving the dryness of the sheet leaving the couch. Lump breaker rolls are normally used on sheets like

kraft liner, corrugating medium, bag paper, and other coarse grades normally run without pick-ups. On printing papers, lump breaker rolls are normally not used, as it accentuates the wire mark.

WIRE RETURN RUN

The wire run between the couch and the breast roll is called the wire return run. The wire is here led over rolls in a zig-zag line. The wire return run is used for cleaning, guiding, stretching, and driving the wire.

The wire must be kept clean, as any spot plugging the wire will give a hole in the paper. Material sticking to the wire will produce dents (when the wire travels around the rolls) and will rapidly wear out the wire (when it passes over stationary surfaces) or produce nonuniformities in the paper. Wrinkles, slack spots, ridges, etc. are equally as detrimental to the final product and wire life.

As the wire is very fragile, great care must be used both in putting it on and in keeping it clean and free from damage. The wire is kept clean by applying water through showers to wash off stock and other material on its return run. All stock must be removed before the wire hits an outside roll. Leaving the couch at a break or under normal operations, the wire contains the full sheet and edge strips, respectively. These must be removed by high pressure showers, "knock-off" showers, before the wire reaches the first wire return roll. Sometimes low-pressure showers are used to help release the sheet ahead of the high-pressure showers. Showers and doctors are today used on almost all outside and inside wire return rolls on high-speed machines to keep the rolls clean. The doctors must fit well to prevent any dirt from accumulating on the rolls to

cause ridges. Inside doctors are provided with guards leading the water outside the wire.

Fresh water is often used on the wire showers, but should then be collected separately, so as not to dilute the white water. Filtered whitewater is being used more and more to reduce the total need of water in the mill.

WIRE GUIDING

Wire guiding is needed to keep the wire on the machine. An automatic sensing device feels the position of the edge of the wire and activates the movement forward and backwards in the machine direction of one end of the guide roll, which is pivoted in the other end. This guide roll is normally placed somewhere in the return run with a wire wrap of between 10 to 15". The wire will run towards the side of the guide roll it meets first. For proper guiding, all elements in the wire must be correctly aligned. In addition to the automatic guide, most machines have manual adjustment of one roll to compensate for minor misalignments.

The wire must be run with the correct tension to insure proper operation of the wire section. For this purpose, one automatic and one manual stretch is normally provided. The automatic stretch will maintain a constant tension in the wire during operation, and the level of tension can be easily controlled. The maximum tension is determined by the strength of the wire. The highest tension exists between the dry suction boxes and the couch and is normally equal to the tension set by the tension device and the drag over the dry suction boxes. As a higher tension over the table rolls normally means better formation and less disturbance, tight wires should normally be run. Dry suction box vacuums should be kept as low as possible to prevent overstretching the wire. Sufficient tension is needed to insure that the drive power can be transmitted to the wire at the in-drive points.

Cylinder Machine Formers (See Cylinder Paper Machines, Chs. 6-9.) The Stevens former can no longer be called a cylinder machine, as the nozzle defining the forming area has no overflow. The nozzle geometry is adjustable to conform to the drainage characteristics of the sheet being made. It uses a normal cylinder mold as the forming roll. The Stevens former is being used mainly as a tissue former for moderate speeds. (Fig. 13.)

The most recent development for multi-cylinder machines is the Kubayashi former, Fig. 14. The sheet is formed on top of a cylinder mold with an

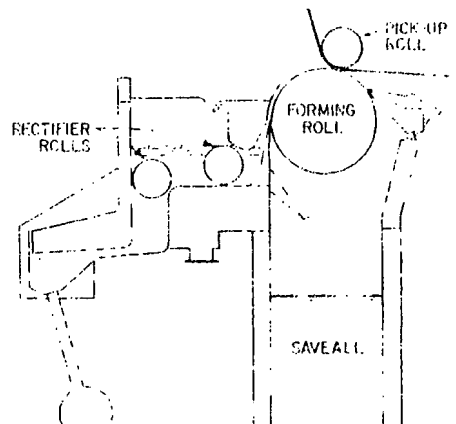


Fig. 13. The Stevens former.

inside suction zone. The jet is laid on top of the forming zone from a headbox. Forming is performed on a circular-free surface, which limits the speed, but gives the same control of forming and basis weight that can be achieved on an open-wire former. By having a horizontal-free run ahead of the circular part for drainage, the speed can be increased. After the free forming area, the sheet meets a felt traveling outside the sheet, thus keeping the sheet onto the cylinder and transferring the sheet to the felt by suction. This former represents a radical improvement in quality control and speed potential for multi-layer machines. Each forming unit has a limited drainage capacity, thus making the former less attractive for single layer forming.

All the above formers, when used for multi-

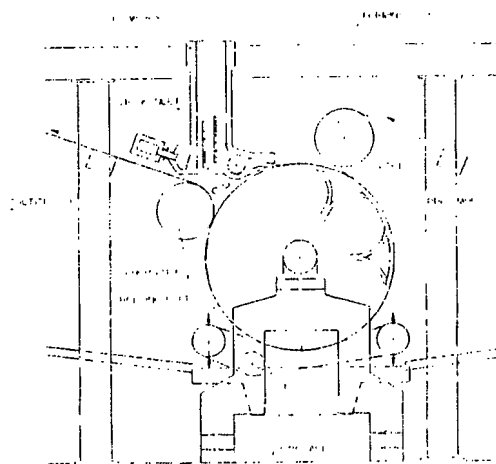


Fig. 14. Kubayashi former

layer boards, are used to form single layers that are couched together on a common pick-up felt. One pick-up felt is used to pick up the sheet from each former in succession.

Suction Breast Roll Formers Very special forming devices have been developed for high-speed manufacture of lightweight sheets, especially tissue and toweling. The suction breast roll former shown in Fig. 20 page 418 is typical for such an arrangement. The former consists of an open grill roll normally with a two-compartment suction box provided either with a wire sleeve or a wire wrapping part of its periphery and a stationary lip extending from the headbox over the forming area that defines the forming zone. The forming length is very short, which limits the usefulness of this former to lightweight sheets. The curvature of the upper lip must conform to the drainage curve of the sheet being formed, making the former most suitable as a single purpose machine. The high shear against the stationary top lip also limits the basis weights and the top speeds for which it can be used. It is today the dominant former for tissue papers and is used at speeds up to 4000 fpm. However, there are indications that a new approach is needed for speeds above 4000 fpm. Two recent developments in suction roll formers are those of Scott, described in *Paper Trade J.*, 152, No. 53, 22, (Dec. 30, 1958), and of Kimberly-Clark, *Paper Trade J.*, 153, No. 6, 40, (Feb. 10, 1969). The Scott forming section is shown in Fig. 15.

Twin Wire Formers Over the last fifteen years, a lot of work has been performed to replace the open fourdrinier with one where the forming takes place between two surfaces—one or both of which can be porous. These formers have the advantage of eliminating the free surface of the fourdrinier, and thus should have a higher speed potential and give better control and uniformity. On formers draining both ways, the forming length can be greatly reduced, and paper with identical surfaces can be produced. A number of these methods are now in commercial operation or in different stages of development. A discussion of forming methods would be incomplete without discussing these new formers, which certainly are going to be increasingly used in the future.

Forming between two surfaces is very different than forming on an open table. Sufficient pressure must be exerted in the forming zone to drain the sheet. This pressure also causes lateral movement of the furnish out of the forming zone, limiting the

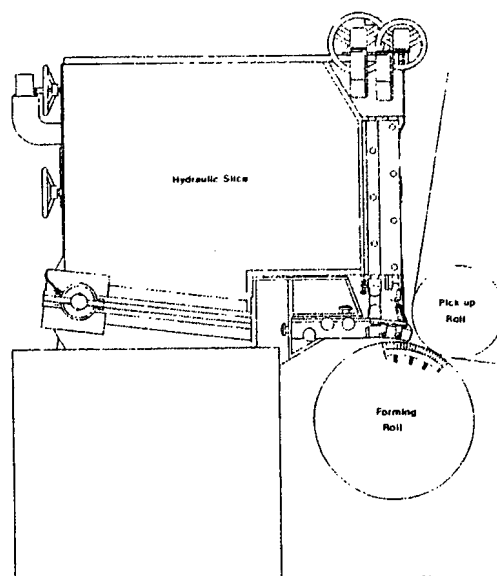


Fig. 15. Scott forming section. (Courtesy Scott Paper Co.)

time and pressure that can be applied in such a former. The drainage capacity of a twin wire former is, therefore, much lower than for an open wire former, limiting its usefulness to papers like newsprint, corrugating medium, bag, and medium weight fine papers. Due to the lower drainage capacity, these papers are made at consistencies that are higher than for open wire formers. To achieve good formation at these consistencies, headboxes with high shear are necessary and are being developed. Twin wire formers have, from necessity, very much shorter forming areas.

The geometry of the forming zone is defined by the two surfaces and in turn determines the pressure distribution in the forming zone. Zero or small pressure gradients are imperative to avoid break-up of the sheet already formed. This necessitates close to constant pressure in the forming zone, which can only be achieved if the forming zone closely corresponds to the drainage curve. As the length and form of the drainage curve varies with pulp, basis weight, speed, consistency, temperature, etc., the importance of forming zone geometry is obvious.

The first successful twin wire former was the "Inverform," Fig. 16. Here a top wire is put on top of a bottom wire, and the stock is injected between the two. In the forming area, the bottom wire is supported between two rolls, and the top wire is supported between the forming roll and a doctor blade that pushes the top wire against it. Water is removed both upwards and downwards. The pres-

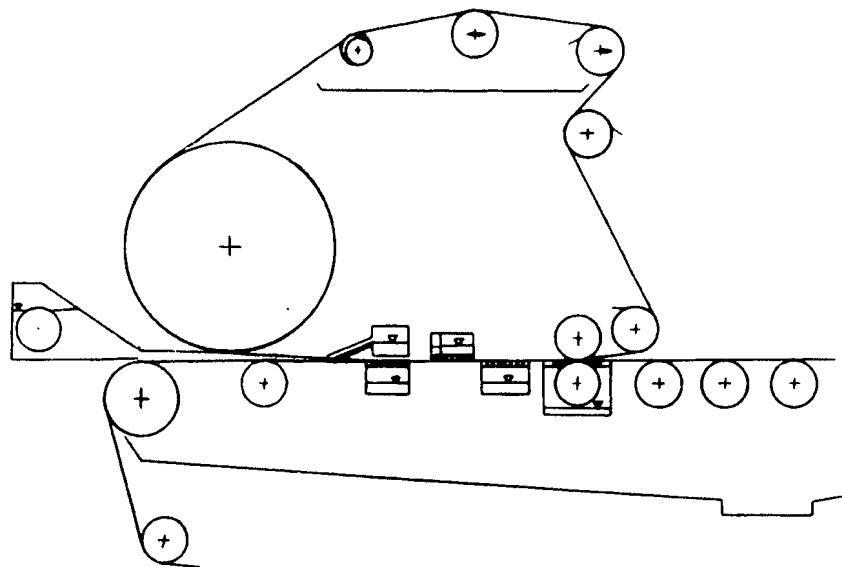


Fig. 16. "Inverform."

sure in the forming zone makes the wires bond outwards in a chain line, thus making a forming zone that deviates greatly from the drainage curve. By using moderate pressures, this Inverform principle has been found useful for forming multi-layer boards at moderate speeds, thus giving a quality and speed higher than existing cylinder machines. Recent modifications have been introduced to overcome some

of the principle shortcomings of the original Inverform.

The Twinverform is an improvement of the Inverform that makes the principle applicable for high-speed manufacture of papers like publication raw stock, newsprint, and other groundwood sheets. Fig. 17. The top wire follows a stationary inverted suction box, with a curved entrance part followed

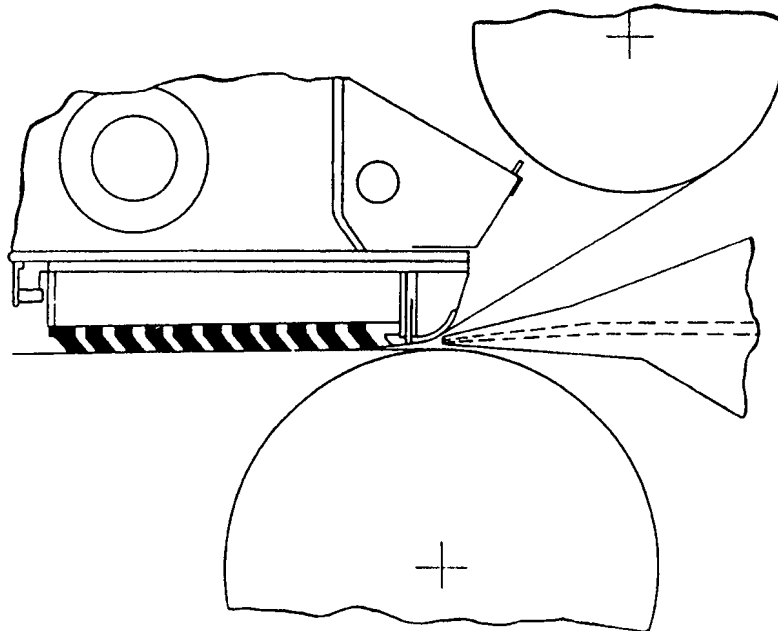


Fig. 17. Beloit Twinver form.

PAPER MACHINE—FORMING SECTION

The Papriformer uses the principal of forming between a porous suction roll and a wire under tension. Fig. 19. As a wire under tension exerts a constant radial pressure when run in a circular path, this former has a constant pressure in the forming zone

PAPRIFORMER

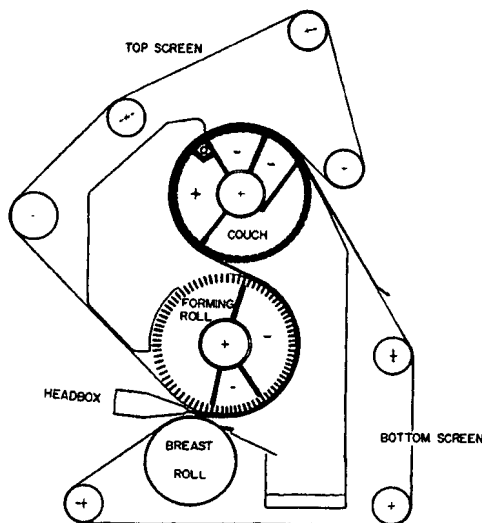


Fig. 19. Papriformer.

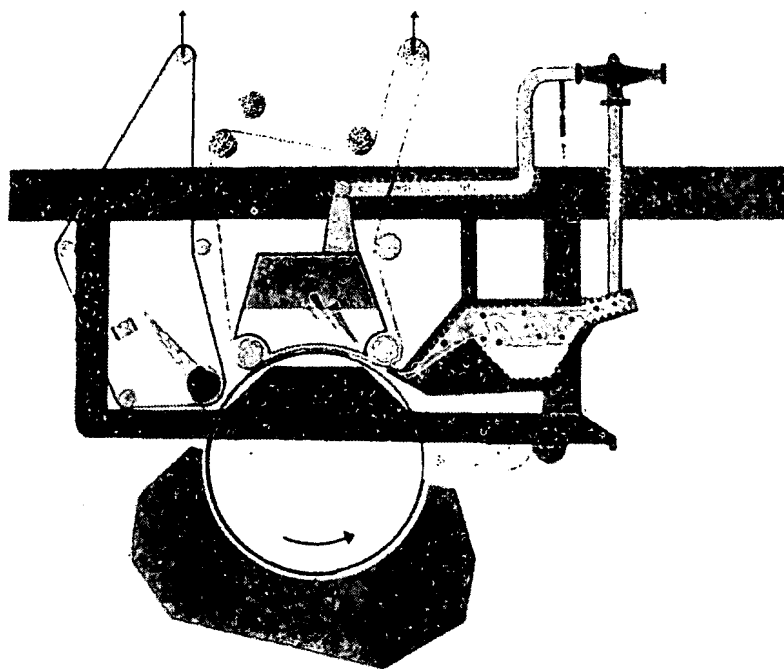


Fig. 20. "Performer."

ing papers have been successfully made on a pilot machine.

The same principle is used in the "Performer" to form lightweight sheets like tissue between a solid roll and a wire under tension (Fig. 20). The excellent properties of this method have been demonstrated in pilot plant tests at speeds up to 5000 fpm. Commercial formers built on this principle, but forming between a felt and a wire, are manufacturing tissue at speeds close to 5000 fpm.

A large number of twin-wire formers are available and new ones are being developed, but it is still too early to predict their final place as paper-making tools. Their limited drainage capacity will automatically exclude them from certain grades, such as linerboard, foodboard, pulp machines, etc., and make them marginal for corrugating media and heavy fine papers. They will enable higher forming speeds than are possible with open wire formers,

and speeds up to 5000 fpm should be no problem. Grades where two equal wire sides are beneficial will be made on twin wire formers. For other grades, the openness of the sheet, the low retention, and the two wire sides might be a handicap. Improved control and uniformity both on basis weight and other properties seems possible. The successful application of twin wires necessitates good headboxes.

It is obvious that the improved open wire formers and the twin wires will be used in parallel on different types of papers.

REFERENCES

1. Burkhard, G. and Wrist, P. E., *Pulp and Paper Mag. Can.*, **57**, No. 4, 100-118, (March 1956).
2. Berkervall, O., Larsson, K. O. and Wahlstrom, B., TAPPI Engineering Conference, 1967.
3. Gavelin, G., "Fourdrinier Papermaking," Lockwood Publishing Co., New York, 1963.